PV POWER SYSTEMS, THE 2002 *NATIONAL ELECTRICAL CODE*®, AND BEYOND*

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ABSTRACT

The 2002 *National Electrical Code® (NEC)®* was legislated into law in many states and cities on January 1, 2002 [1]. Article 690 of the *NEC*, which covers photovoltaic power systems, contains changes that will affect how photovoltaic systems are installed and inspected over the next three years. More than 30 changes were made in Article 690 in the 2002 *NEC*. While some of these were merely editorial and format changes, many dealt with technical requirements associated with disconnects, batteries, and wiring. Additionally, sections of this article were revised for clarity and several definitions were added. This paper presents the important technical revisions accepted in Article 690 of the 2002 *NEC*. Work has already begun on revising Article 690 of the 2002 Code for publication in the 2005 *NEC*. Proposed changes ranging from additional clarifications to new language allowing ungrounded photovoltaic arrays are being considered as proposals for the 2005 *NEC*.

CHANGES FOR ARTICLE 690 OF THE 2002 *NEC*

Changes to Article 690 "Solar Photovoltaic Power Systems" of the 2002 *NEC* were proposed through the efforts of nearly 60 participants from the Photovoltaic Industry. More than 90% of the proposed changes now appear in the 2002 *NEC*. The *NEC* has been legislated into law in many states and municipalities throughout the United States and affects how photovoltaic systems are installed. The 2002 *NEC* Handbook was also updated and now provides new and additional explanatory information for many of the sections in Article 690 including some of those that were unchanged in the 2002 *NEC* [2].

690.2 Definitions

Definitions that were added in 2002 include "Bipolar Photovoltaic Array," "Photovoltaic Systems Voltage," and "Diversion Charge Controller." The new definitions for bipolar photovoltaic array and diversion charge controller were added to cover oversights in the previous edition. Monitoring fielded installations discovered the need for new definitions and two sections in Article 690.

690.3 Other Articles

Article 690 requirements still apply when they conflict with any other article of the *NEC*. Reference is now made to sections 705.14, 705.16, 705.32, and 705.43 that provide the compatibility requirements for grounding, synchronizing and ground-fault protection when there is more than one source of power like the utility grid. These other articles generally won't affect new photovoltaic installations other than requiring system compatibility that is already required by Article 690. The listed inverters used in today's photovoltaic systems are capable of meeting the requirements found in the 705 sections.

690.5(B) Disconnection of Conductors

This ground-fault protection equipment section was reworded to correct a grammatical error and to better match the functions of existing equipment. There are no changes from the detailed requirements established back in the 1987 *NEC* for this fire protection device that must be used in photovoltaic systems with modules mounted on the roofs of dwellings. It still must detect the ground fault, indicate that a ground fault has occurred, interrupt the fault current, and disconnect the faulted photovoltaic array or photovoltaic source circuit. In utility-interactive systems, turning the inverter off has been generally accepted as equivalent to disconnecting the photovoltaic source circuit.

690.7(E) Bipolar Source and Output Circuits

A new section was added to define the dc voltage-to-ground as the photovoltaic system voltage on certain types of bipolar systems that use separate sub-arrays and that meet specific grounding requirements including labeling pertaining to hazards associated with disconnecting the ground connection. There are no commercially available inverters today that use bipolar photovoltaic arrays, although some recent vintage inverters did. Most bipolar systems require that the system voltage be measured between the two highest voltage conductors (usually the positive and negative monopole voltages).

690.8(B) Ampacity and Overcurrent Device Ratings

Changes now designate that photovoltaic currents are to be considered continuous (lasting more than three hours). This is important to the photovoltaic design process because the solar irradiance usually exceeds the standard test conditions of 1000 watts per square meter for three hours or more around solar noon. This is the reason for the 125% multiplier on current that is applied to dc photovoltaic source and output circuits. An additional 125% is applied to nearly all electrical circuits to prevent

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overcurrent devices from operating at more than 80% of rating. The section was revised and reformatted for clarity.

690.8(D) Sizing the Module Interconnection Conductors

This entire section was added to ensure that the module cables have sufficient ampacity when only one overcurrent device is used to protect two or more strings of modules. This is a complex subject and designers must consider the photovoltaic module ratings and the conductors. Normally, an overcurrent device will be needed for each module or string of modules and the conductors and overcurrent devices will be sized as required by other sections of Article 690.

690.9(C) Photovoltaic Source Circuits

The section was modified to indicate that supplementary overcurrent devices are available in one-amp increments up to 15 amps. Both dc listed fuses and circuit breakers are available in these values and some of the new thin-film photovoltaic modules may require overcurrent protection as low as 1-2 amps.

690.9(E) Series Overcurrent Protection

The *NEC* now permits (note permissive, not mandatory language) the use of only a single overcurrent device in a series string of modules. The clarification was added because some inspectors were asking for one fuse per module and/or a module fuse and a conductor fuse in a series string.

690.14 Additional Provisions

Code Making Panel-3 (CMP-3) voted to remove a misleading reference to Article 230, by revising this section to put the requirements of Part 230F into Article 690. There are no real changes in the requirements. They are now just repeated in 690.14. The language requires that the photovoltaic disconnect be readily accessible outside the building or immediately inside the building at the point of first penetration of the building. Although not a code requirement, some inspectors have required that this disconnect be grouped with the disconnects for other sources of power for the building.

This disconnect location restricts the practice of running photovoltaic conductors through the roof inside the attic and inside the house to a first disconnect near the batteries or the utility-interactive inverter. The photovoltaic source circuits must now be run outside the building to a readily-accessible point outside the building or to a point immediately inside the building to the first disconnect. “Readily accessible” means no ladders can be used to get to disconnects mounted on the roofs or other high locations and parts of the building may not be moved to get to the switches. PV Disconnect switches cannot be mounted in bathrooms due to the potential shock hazards.

Grouping the disconnects is a very old requirement and means that the photovoltaic, wind, utility, hydro, generator, etc., shall all be grouped in the same location. Although the battery is not considered a source of power in Article 690, many inspectors consider it to be and it certainly acts like a source of power, so it is probably best to group the battery disconnects with the others.

A label or placard is needed on the outside of the building indicating where all disconnects are located if they are not readily visible. All of these requirements have been in the code for years, but they are now specifically spelled out in Article 690.

690.45 Size of the Equipment Grounding Conductor

This section was added to reflect recent research that shows that the equipment-grounding conductors for module source and output circuits must essentially be as large as the circuit conductors (at least they must have an ampacity of 1.25 times the short-circuit current). Over sizing the equipment-grounding conductors when the circuit conductors are oversized for voltage drop is still required, but they don't have to be any larger than the circuit conductors. If the system is protected by a ground-fault detection device (Section 690.5), then the equipment-grounding conductors are to be sized according to Section 250.122 where sizes of the equipment-grounding conductors are based on the overcurrent device protecting that circuit.

690.47 Grounding Electrode System

Code Making Panel-3 (CMP-3) revised this section into two parts. Section (A) addresses alternating-current (ac) grounding and (B) addresses direct-current (dc) grounding. All the section really does is refer back to the appropriate ac or dc grounding sections in Article 250.

690.55 Photovoltaic Power Systems Employing Energy Storage

This new section requires a label that will show the maximum operating voltage (including any equalizing voltage) of the system and the polarity of the grounded conductor. Although most photovoltaic systems use a negative ground, some telecommunications systems use positive grounds. The label should be placed near the main system disconnects.

690.56 Identification of Power Sources

Part (A) deals with the marking required on the outside of buildings with stand-alone photovoltaic systems. Part (B) covers the exterior markings on buildings that have utility service and photovoltaic systems. In both cases, the requirement is to indicate the locations of the main disconnects for all sources of power to a building including renewable, utility, or back-up generator sources.

690.71(D) Battery Nonconductive Cases and Racks

This section requires that flooded, lead-acid battery systems operating at over 48-volts nominal (24, 2-volt cells) have nonconductive racks and cases to minimize the potential for leakage currents, carbon tracks, shocks, and explosions. Leakage incidents have been a problem on batteries in high-voltage battery banks (100-500 volts). This requirement does not apply to valve-regulated lead-acid batteries (VRLA) that are sealed because some of them require steel cases and they normally don't pose similar hazards.

690.71(E) Disconnection of Series Battery Circuits

This section requires that battery banks operating at more than 48 volts nominal have provisions to disconnect the series-connected cells into sets of 24 cells or fewer for servicing. Bolted or plug-in non-load-break disconnects are allowed for this application.

690.71(F) Battery Maintenance Disconnecting Means

A disconnect (for use by qualified persons only) is now required to open the grounded conductor of battery banks operating above 48 volts nominal. This disconnect may be a non-load-break switch and it may not unground the rest of the photovoltaic system.

690.71(G) Battery Systems of More Than 48 Volts

These battery systems may be (permissive, not required, language) operated with ungrounded conductors if several conditions are met. The photovoltaic array must be grounded. Any ac and dc load circuits must be grounded. The first two conditions are probably going to be met by inverters that provide internal ground-circuit isolation among the photovoltaic array, the load circuits, and the battery system. All ungrounded input/output battery circuit conductors will be required to have switched disconnects and overcurrent protection. A ground-fault detector will be required to monitor the battery bank for ground faults.

690.72(B) Diversion Charge Control

(1) This new section requires that any system using a diversion charge controller have a second independent method of charge control. With diversion controllers, if the diversion circuit fails, the batteries may be overcharged and can pose hazards (explosions, smoke, and fire). This requirement would apply to both ac and dc diversion controllers.

The requirement would be similar to the back-up methods used with inverters that sell excess photovoltaic and battery energy to the grid. If the grid fails, a backup controller is normally installed to keep the batteries from being over charged.

(2) The current rating of the dc diversion load, the ampacity of the diversion load circuits, and the rating of the overcurrent device protecting those circuits will be at least 150% of the current rating of the charge controller. Of course, the diversion charge controller should be sized to handle the total output of the renewable source under worst-case conditions. See the note below on revising this requirement for clarity in the 2005 *NEC*.

AREAS UNDER CONSIDERATION FOR THE 2005 *NEC*

Since it takes nearly three years to revise each edition of the *NEC*, the process of developing the 2005 *NEC* has already started. Although the 2002 *NEC* has just been published, it represents the state-of-the-art as of mid 1999 when the changes were proposed. Changes and additions to the new 2002 Code are needed to keep up with recent safety requirements and findings and new technology developments.

Work is starting on the 2005 *NEC* and the initial proposals and their substantiation must be submitted by November 1, 2002 [3]. Anyone may submit well-substantiated proposals to the National Fire Protection Association (NFPA) for consideration by the code-making panels. Since NFPA, Underwriters Laboratories (UL), Institute of Electrical and Electronic Engineers (IEEE), International Association of Electrical Inspectors (IAEI), and other organizations have members on the code-making panels, the substantiation for proposals should address any requirements and concerns that those organizations might have, such as compliance with other electrical-industry wide requirements. For example, a proposal suggesting that unlisted cables be used in photovoltaic systems would not receive much support by the panel members unless it had armor-plated substantiation.

The following items are being discussed and considered by the PV Industry and may be proposed for inclusion in the 2005 *NEC*. For those items proposed and accepted for the 2005 *NEC*, appropriate changes and explanations will also be added to the 2005 *NEC* Handbook.

Inverter Input Currents

Stand-alone inverters have dc input currents that contain load-dependent ac ripple currents that often exceed the average or dc currents. The RMS (root-mean-square) value of these currents plus the average or dc current is the current value that heats conductors and causes overcurrent devices to function.

Question: Should the largest RMS current and the average current be marked on the inverter? These values then may be used to determine required cable ampacity and overcurrent device ratings [4].

Ungrounded Photovoltaic Arrays

Question: Should photovoltaic arrays be installed without a system ground as is done in Europe and Japan? Ungrounded systems can be as safe as grounded systems if safety factors such as double insulation, double-pole disconnects, double-pole overcurrent devices, and ground-fault detection devices are implemented [5,6].

Warning Label on Inverter

Question: Should the warning required by NEC 690.5(C) be made part of the UL-required marking on the inverter?
The warning states that a ground-fault indication may mean that the normally grounded circuit conductors are no longer grounded and may be energized.

Grounding Methods for Inverters

Question: Should inverters that ground the photovoltaic array inside the inverter be required to have an external label stating the grounding method?
Question: Should inverter terminals be large enough to accept code-required grounding-electrode conductors?

Sizes of Overcurrent Devices

Question: Should the 1-amp increments on overcurrent devices rated below 15 amps mentioned in 690.9(C) also be referenced in Article 240 and elsewhere in Article 690?

Specifications for DC Photovoltaic Disconnects

Question: Should a new set of specifications be developed for the dc disconnects used in PV systems and should they be incorporated into an appropriate UL Standard?
The rationale for this question relates to the fact that photovoltaic arrays present limited short-circuit currents. Photovoltaic disconnects may only be used dozens of times, not thousands of times, over the life of the system and are not subjected to high interrupt currents.

Ground-Fault Detection Devices

Question: Should photovoltaic systems be equipped with ground-fault detection systems that can detect leakage currents at levels that might pose shock hazards and if so how would the array size be addressed?

Plug and Play System Requirements

Question: What will the most advanced "plug-n-play" photovoltaic systems look like and what are the safety issues that need to be addressed in the NEC?
Plug and play systems should effectively isolate the consumer from all hazardous voltages.

Diversion Load Rating

Question: Does the size rating of the diversion load as required by 690.72(B)(2) need to be changed from a current rating to a power rating?
The current rating of the load must match the rating of the associated charge controller. The ability to accept higher currents requires that the power handling capability of the diversion load be higher than a rating based on current.

Photovoltaic Array vs. Battery Size

Question: Should PV systems with small battery banks in relation to the size of the photovoltaic array have a backup method of preventing the batteries from being overcharged in the event the primary charge controller fails?
Many utility-interactive photovoltaic systems are being installed with small battery systems to provide a limited ability to supply critical on-site loads when the utility is not present. These systems normally rely on the utility to absorb excess energy for the photovoltaic system.

Grounding Requirements

Question: Should the grounding requirements, where the photovoltaic systems contain both stand-alone and utility-interactive components, be clarified in Article 690?

External Battery Disconnects

Question: Should systems employing batteries have a readily-accessible, external-to-the-building disconnect (directly or remotely controlled) that can be used by emergency-response personnel to shut the system down?
Battery systems, while not a source of energy, do store considerable amounts of energy.

SUMMARY

The changes in Article 690 of the 2002 *NEC* addressed previous oversights and make it more definitive and clearer to ensure safe installations. The revisions to the comments in the 2002 *NEC Handbook* also make it easier for the people to understand the rationale behind the Code requirements. Informal discussions for proposed changes to the 2005 *NEC* are underway and are expected to result in proposals to make the *National Electrical Code* in 2005 more comprehensive and understandable while providing more flexibility in photovoltaic installations.

REFERENCES:

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4. *UL Standard for Static Converters and Charge Controllers for Use in Photovoltaic Power Systems, UL1741,* Underwriters Laboratories, Jan 2001.

5. Utility Aspects of Grid Interconnected PV Systems, IEA-PVPS Report, IEA-PVPS T5-01: 1998, Dec 1998.

6. Bower, W., Wiles, J., "Analysis of Grounded and Ungrounded Photovoltaic Systems," Proceedings of the 1st World Conference on Photovoltaic Energy Conversion, Waikoloa, HI, Dec 5-9, 1994.